of tendon, of the cornea, or of epithelium. He advances arguments to show that the epithelium-like tissue upon the summit of the papilla is not epithelium at all, but belongs to the nervous tissues. Hence it follows that nerves do not influence any tissues by reason of continuity of tissue, but solely by the nerve-currents which pass along them*.

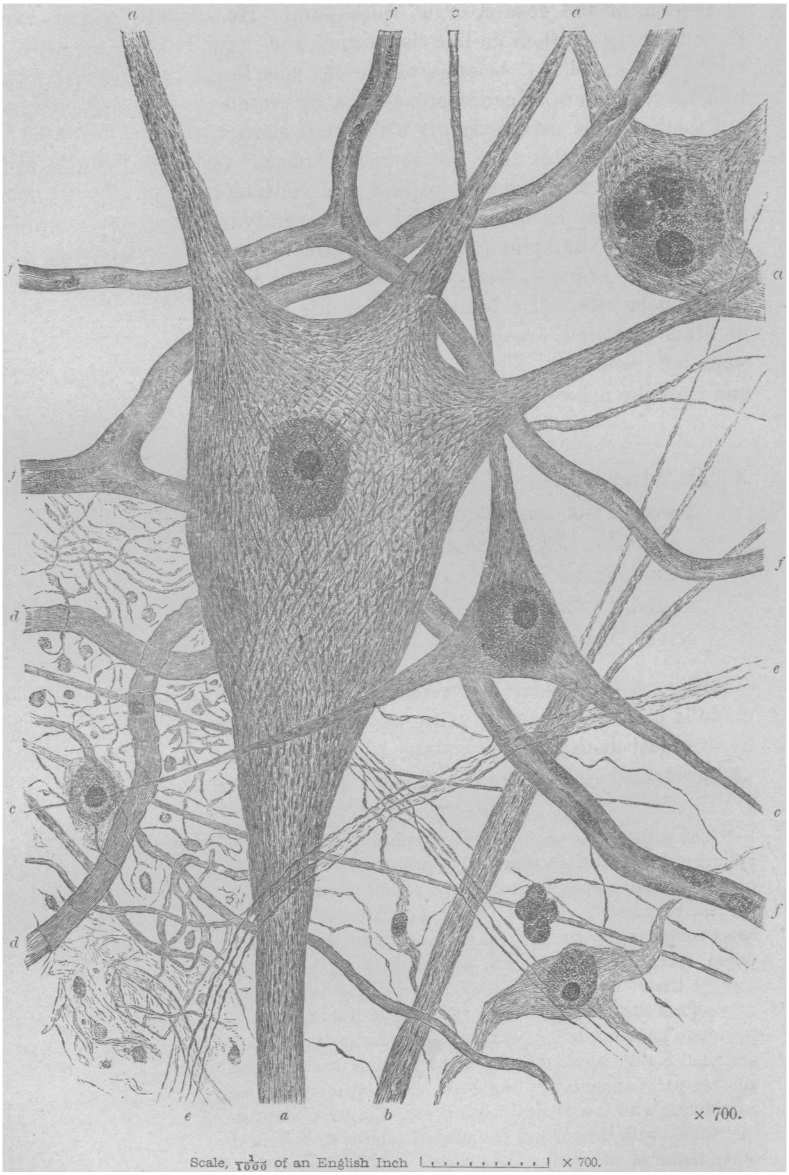
The author states that the so-called 'nuclei' (germinal matter) of the fine muscular fibres of the papillæ are continuous with the contractile material, as may be demonstrated by a magnifying power of 1800 linear; and he holds the opinion that the contractile matter is formed from the nuclei. He adduces observations which lead him to the conclusion that these nuclei alter their position during life, and that, as they move in one or other direction, a narrow line of new muscular tissue (fibrilla) is as it were left behind†. This is added to the muscular tissue already formed, and thus the muscle increases.

XXII. "Indications of the Paths taken by the Nerve-currents as they traverse the caudate Nerve-cells of the Spinal Cord and Encephalon." By LIONEL S. BEALE, M.B., F.R.S., F.R.C.P., Professor of Physiology and of General and Morbid Anatomy in King's College, London; Physician to the Hospital, &c. Received May 18, 1864.

Although the caudate nerve-vesicles, or cells existing in the spinal cord, medulla oblongata, and in many parts of the brain, have been described by the most distinguished modern anatomists, there yet remains much to be ascertained with reference to their internal structure, connexions, and

* The author feels sure that the conclusions of Kühne, who maintains that the axis cylinder of a nerve-fibre is actually continuous with the 'protoplasm' (germinal matter) of the corneal corpuscle, result from errors of observation. The prolongations of the corneal corpuscles, on the contrary, pass over or under the finest nerve-fibres, but are *never* continuous with them, as may be distinctly proved by examining properly prepared specimens under very high magnifying powers (1000 to 5000 linear). The corneal tissue results from changes occurring in one kind of germinal matter—the nerve-fibres distributed to the corneal tissue from changes occurring in another kind of germinal matter. If the connexion is as Kühne has described, a 'nucleus' or mass of germinal matter would be producing nervous tissue in one part and corneal tissue in another part; and since it has been shown that the 'nuclei' of the corneal tissue are continuous with the corneal tissue itself, the nerve-fibres must be continuous, through the nuclei, with the corneal tissue itself; and if with corneal tissue, probably with every other tissue of the body. But such a view is opposed to many broad facts, and not supported by minute observation. The nuclei of the nerve-fibres are one thing, the nuclei of the corneal tissues another; and the tissues resulting from these nuclei, nerve-tissue, and corneal tissue are distinct in chemical composition, microscopical characters, and properties and actions.

† "New Observations upon the Movements of the Living or Germinal Matter of the Tissues of Man and the higher Animals," Archives, No. XIV. p. 150.



Large candate nerve cell, with smaller cells and nerve fibres, from a thin transverse section of the lower part of the grey matter of the medulla oblongata of a young dog. The specimen had been soaked for some weeks in acetic acid and glycerine. The lines of dark granules resulting from the action of the acid are seen passing through the very substance of the cell in very definite directions. Thus the cell is the point where lines from several distant parts intersect (Diagram, Fig. 2). It is probable that each of these lines is but a portion of a complete circuit (see Diagram in Fig. 3). A, A, A, large fibres which leave the cell. B, a fibre from another cell, dividing into finer fibres, exhibiting several lines of granules. C, C, C, fibres from a younger candate nerve vesicle. D, fine and flattened dark-bordered fibres. E, three fine nerve fibres running together in a matrix of connective tissue. F, F, F, capillary vessels.

L. S. B. del. 1863.

mode of development. In this paper I propose to describe some points of interest in connexion with their structure. In the first place, however, I would remark that there are neither '*cells*' nor '*vesicles*' in the ordinary acceptation of these words, for there is no proper investing membrane, neither are there '*cell-contents*' as distinguished from the *membrane* or *capsule*; in fact the so-called cell consists of soft solid matter throughout. The nerve-fibres are not prolonged from the nucleus or from the outer part of the cell, but they are continuous with the very material of which the substance of the 'cell' itself is composed, and they are, chemically speaking, of the same nature. So that in these caudate cells we have but to recognize the so-called '*nucleus*' (*germinal matter*) and *matter around this* (*formed material*) *which passes into the* '*fibres*,' which diverge in various directions from the cell: see Plate III. (fig. 1).

At the outer part of many of these 'cells,' usually collected together in one mass, are a number of granules. These are not usually seen in the young cells, and they probably result from changes taking place in the matter of which the substance of the cell is composed. But it is not proposed to discuss this question in the present paper.

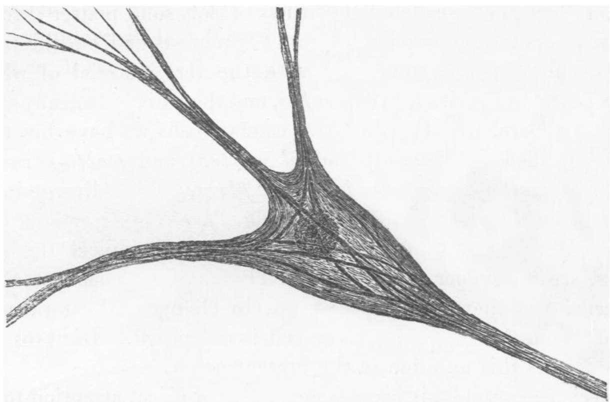
My special object in this communication is to direct attention to a peculiar appearance I have observed in these cells, which enables me to draw some very important inferences with reference to the connexions and action of these very elaborate and most important elements of the nervous mechanism.

In some very thin sections of the cord and medulla oblongata of a young dog, which had been very slowly acted upon by dilute acetic acid, the appearances represented in Plate III. (fig. 1) were observed. Subsequently, similar appearances, though not so distinct, have been demonstrated in the caudate nerve-vesicles of the grey matter of the brain of the dog and cat, as well as of the human subject. I have no doubt that the arrangement is constant, and examination of my specimens will probably satisfy observers that the appearance is not accidental. Each fibre (*a*, *a*, *a*) passing from the cell exhibits in its substance several lines of granules. The appearance is as if the fibre were composed of several very fine fibres imbedded in a soft transparent matrix, which fibres, by being stretched, had been broken transversely at very short intervals. At the point where each large fibre spreads out to form the body of the cell, these lines diverge from one another and pursue different courses through the very substance of the cell, in front of, and behind, in fact around the nucleus. Lines can be traced from each fibre across the cell into every other fibre which passes away from it. The actual appearance is represented in Plate III.; and in the diagram, fig. 2, a plan of a 'cell,' showing the course of a few of the most important of these lines which traverse its substance, is given.

I do not conceive that these lines represent fibres structurally distinct from one another, but I consider the appearance is due to some difference in composition of the material forming the substance of the cell in these

particular lines; and it seems to me that the course which the lines take permits of but one explanation of the appearance. Supposing nerve-currents to be passing along the fibres through the substance of the cell,

Fig. 2.



A diagram of such a cell as that represented in Plate III. (fig. 1), showing the principal lines diverging from the fibres at the point where they become continuous with the substance of the cell. These lines may be traced from one fibre across the cell, and may be followed into *every other fibre* which proceeds from the cell.

they would follow the exact lines here represented; and it must be noticed that these lines are more distinct and more numerous in fully-formed than in young cells. They are, I think, lines which result from the frequent passage of nerve-currents in these definite directions.

Now I have already advanced arguments in favour of the existence of complete nervous circuits, based upon new facts resulting from observations upon *a*, the peripheral arrangement of the nerves in various tissues*; *b*, the course of individual fibres in compound trunks, and the mode of branching and division of nerve-fibres†; and *c*, the structure of ganglion-cells‡. I venture to consider these lines across the substance of the caudate nerve-cells as another remarkable fact in favour of the existence of such circuits; for while the appearance would receive a full and satisfactory explanation upon such an hypothesis, I doubt if it be possible to suggest another explanation which would seem even plausible.

Nor would it, I think, be possible to adduce any arguments which would so completely upset the view that nerve-force passes centrifugally from one

* Papers in the Phil. Trans. for 1860 and 1862. Lectures on the Structure of the Tissues, at the College of Physicians, 1860.

† "On very fine Nerve-fibres, and on Trunks composed of very fine Fibres alone," Archives of Medicine, vol. iv. p. 19. "On the Branching of Nerve-trunks, and of the subdivision of the individual fibres composing them," Archives, vol. iv. p. 127.

‡ Lectures at the College of Physicians. Papers in Phil. Trans. for 1862 and 1863.

cell, as from a centre, towards its peripheral destination, as this fact. So far from the fibres *radiating from one cell,* or from the nucleus as some suppose, in different directions, *all the fibres which reach the cell* are complex, and contain lines which *pass* uninterruptedly *through it into other fibres.* Instead of the cell being the point from which nerve-currents *radiate* in different directions along single fibres, it is the common point where a number of circuits having the most different distribution intersect, cross, or decussate. The so-called *cell is a part of a circuit,* or rather *of a great number of different circuits.*

Fig. 3.

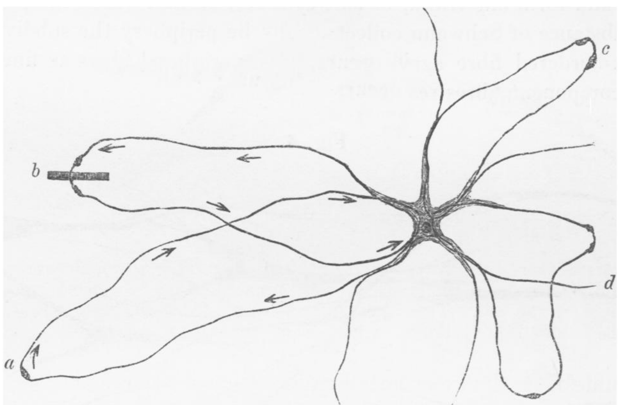


Diagram to show the possible relation to one another of various circuits traversing a single caudate nerve-cell. *a* may be a circuit connecting a peripheral sensitive surface with the cell; *b* may be the path of a motor impulse; *c* and *d* other circuits passing to other cells or other peripheral parts. A current passing along the fibre *a* might induce currents in the three other fibres, *b, c, d,* which traverse the same cell.

I conclude that at first the formed material of the cell is quite soft and almost homogeneous, but that as currents traverse it in certain definite lines, difference in texture and composition is produced in these lines, and perhaps after a time they become more or less separated from one another, and insulated by the intervening material.

It may perhaps be carrying speculation upon the meaning of minute anatomical facts too far to suggest that a nerve-current traversing one of these numerous paths or channels through the cell may influence all the lines running more or less parallel to it (fig. 3).

I have ascertained that fibres emanating from different caudate nerve-cells situated at a distance from one another (fig. 4, *a, a*) at length meet and run on together as a compound fibre (*b, b, b*), so that I am compelled to conclude (and the inference is in harmony with facts derived from observations of a different kind) that every single nerve-fibre entering into the formation of the trunk of a spinal nerve, or single fibre passing from a

ganglion, really consists of several fibres coming from different and probably very distant parts. In other words, I am led to suppose that a single dark-bordered fibre, or rather its axis-cylinder, is the common channel for the passage of many different nerve-currents having different destinations. It is common to a portion of a great many different circuits. The fibres which result from the subdivision of the large fibre which leaves the cell become exceedingly fine (the $\frac{1}{100,000}$th of an inch in diameter or less), and pursue a very long course before they run parallel with other fibres. As the fibres which have the same destination increase in number, the compound trunk becomes gradually thicker and more distinct. The several individual fibres coalesce and form one trunk, or axis-cylinder, around which the protective white substance of Schwann collects. At the periphery the subdivision of the dark-bordered fibre again occurs, until peripheral fibres as fine as the central component fibres result*.

Fig. 4.

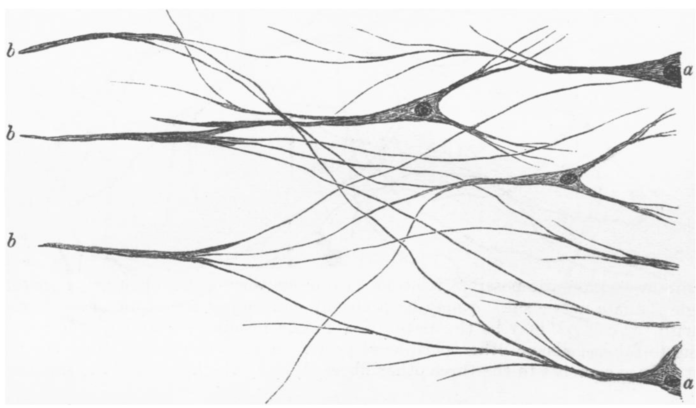


Diagram to show the course of the fibres which leave the caudate nerve-cells. *a, a* are parts of two nerve-cells, and two entire cells are also represented. Fibres from several different cells unite to form single nerve-fibres, *b, b, b*. In passing towards the periphery these fibres divide and subdivide; the resulting subdivisions pass to different destinations. The fine fibres resulting from the subdivision of one of the caudate processes of a nerve-cell may help to form a vast number of dark-bordered nerves, but it is most certain that *no single process ever forms one entire axis-cylinder*.

Although it may be premature to devise diagrams of the actual arrangement, if I permit myself to attempt this, I shall be able to express the inferences to which I have been led up to the present time in a far more intelligible manner than I could by description. But I only offer these schemes as rough suggestions, and feel sure that further observation will

* "General Observations upon the Peripheral Distribution of Nerves," my 'Archives,' iii. p. 234. "Distribution of Nerves to the Bladder of the Frog," p. 243. "Distribution of Nerves to the Mucous Membrane of the Epiglottis of the Human subject," p. 249.

enable me to modify them and render them more exact. The fibres would in nature be infinitely longer than represented in the diagrams. The cell below *c* (fig. 5) may be one of the caudate nerve-cells in the anterior root of a spinal nerve, that above *b* one of the cells of the ganglion upon the posterior root, and *a* the periphery. I will not attempt to describe the course of these fibres until many different observations upon which I am now engaged are further advanced, but I have already demonstrated the passage of the fibres from the ganglion-cell into the dark-bordered fibres as represented in the diagram.

Fig. 5.

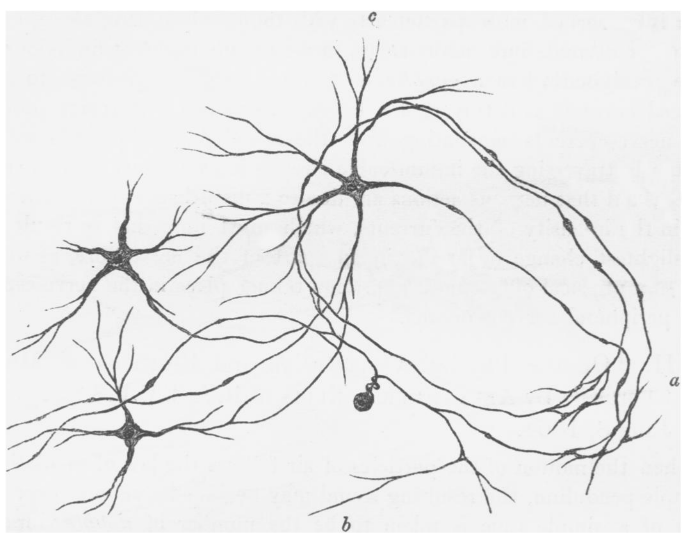


Diagram to show possible relation of fibres from caudate nerve-cells, and fibres from cells in ganglia, as, for example, the ganglia on the posterior roots. *a* is supposed to be the periphery; the cell above *b* one of those in the ganglion. The three caudate cells resemble those in the grey matter of the cord, medulla oblongata, and brain.

The peculiar appearance I have demonstrated in the large caudate cells, taken in connexion with the fact urged by me in several papers, that no true termination or commencement has yet been demonstrated in the case of any nerve, seems to me to favour the conclusion that the action of a nervous apparatus results from varying intensities of continuous currents which are constantly passing along the nerves during life, rather than from the sudden interruption or completion of nerve-currents. So far from any arrangement having been demonstrated in connexion with any nervous structure which would permit the sudden interruption and completion of a current, anatomical observation demonstrates the structural continuity of all nerve-fibres with nerve-cells, and, indirectly through these cells, with one another.

I venture to conclude that the typical anatomical arrangement of a nervous mechanism is not a *cord with two ends—a point of origin and a terminal extremity*, but a cord *without an end—a continuous circuit.*

The peculiar structure of the caudate nerve-cells, which I have described, renders it, I think, very improbable that these cells are *sources* of nervous power, while, on the other hand, the structure, mode of growth, and indeed the whole life-history of the rounded ganglion-cells render it very probable that they perform such an office. These two distinct classes of nerve-cells, in connexion with the nervous system, which are very closely related, and probably, through nerve-fibres, structurally continuous, seem to perform very different functions,—the one *originating* currents, while the other is concerned more particularly with the distribution of these, and of secondary currents induced by them, in very many different directions. A current originating in a *ganglion-cell* would probably give rise to many induced currents as it traversed a *caudate nerve-cell.* It seems probable that nerve-currents emanating from the rounded ganglion-cells may be constantly traversing the innumerable circuits in every part of the nervous system, and that nervous actions are due to a disturbance, perhaps a variation in the intensity of the currents, which must immediately result from the slightest change occurring in any part of the nerve-fibre, as well as from any physical or chemical alteration taking place in the nerve-centres, or in peripheral nervous organs.

XXIII. "On the Physical Constitution and Relations of Musical Chords." By Alexander J. Ellis, F.R.S., F.C.P.S.* Received June 8, 1864.

When the motion of the particles of air follows the law of oscillation of a simple pendulum, the resulting sound may be called a *simple tone.* The *pitch* of a simple tone is taken to be the number of *double* vibrations which the particles of air perform in one second. The greatest elongation of a particle from its position of rest may be termed the *extent* of the tone. The *intensity* or loudness is assumed to vary as the square of the extent. The tone heard when a tuning-fork is held before a proper resonance-box is simple. The tone of wide covered organ-pipes and of flutes is nearly simple.

Professor G. S. Ohm has shown mathematically that all musical tones whatever may be considered as the algebraical sum of a number of simple tones of different intensities, having their pitches in the proportion of the numerical series 1, 2, 3, 4, 5, 6, 7, 8, &c. Professor Helmholtz has established that this mathematical composition corresponds to a fact in nature, that the ear can be taught to hear each one of these simple tones separately, and that the character or *quality* of the tone depends on the law of the intensity of the constituent simple tones.

These constituent simple tones will here be termed indifferently *partial*

* The Tables belonging to this Paper will be found after p. 422.